(11) Japanese Unexamined Patent Application Publication No. 9-167936

(54) [Title of the Invention] SURFACE ACOUSTIC WAVE DEVICE

(57) [Abstract]

[Object] An object is to provide a surface acoustic wave device having a wide bandwidth and having a superior squareness ratio in a high frequency region in which the added mass effect of electrodes becomes prominent.

[Solving Means] The cut angle of a $LiTaO_3$ or $LiNbO_3$ θ rotated Y-X substrate is optimized to be a higher angle than a conventional angle with respect to the added mass of electrodes.

[Claims]

[Claim 1] A surface acoustic wave device having a piezoelectric substrate and an electrode pattern that contains Al as a main component and that is formed at a surface of the piezoelectric substrate,

the surface acoustic wave device being characterized in that the electrode pattern has a thickness in the range of 0.03 to 0.15 of a wavelength of a surface acoustic wave excited on the piezoelectric substrate; and the piezoelectric substrate has an orientation in which a $LiTaO_3$ single crystal is rotated with an angle in the range of 38 to 46° about an X axis from a Y axis toward a Z axis.

[Claim 2] The surface acoustic wave device according to claim 1, characterized in that the piezoelectric substrate has an orientation in which the $LiTaO_3$ single crystal is rotated with an angle in the range of 40 to 46° about the X axis from the Y axis toward the Z axis.

[Claim 3] The surface acoustic wave device according to claim 1 or 2, characterized in that the electrode pattern has a thickness in the range of 0.07 to 0.15 of the wavelength of the surface acoustic wave excited on the piezoelectric substrate.

[Claim 4] The surface acoustic wave device according to one of claims 1 to 3, characterized in that the electrode pattern has a thickness in the range of 0.05 to 0.10 of the

wavelength of the surface acoustic wave excited on the piezoelectric substrate and the piezoelectric substrate has an orientation in which the $LiTaO_3$ single crystal is rotated with an angle in the range of 40 to 44° about the X axis from the Y axis toward the Z axis.

[Claim 5] The surface acoustic wave device according to claim 1, characterized in that the piezoelectric substrate has an orientation in which the $LiTaO_3$ single crystal is rotated with an angle in the range of 42° about the X axis from the Y axis toward the Z axis.

[Claim 6] The surface acoustic wave device according to one of claims 1 to 5, characterized in that the electrode pattern is made of Al.

[Claim 7] The surface acoustic wave device according to one of claims 1 to 5, characterized in that the electrode pattern is made of an Al-Cu alloy.

[Claim 8] The surface acoustic wave device according to one of claims 1 to 7, characterized in that the electrode pattern defines a plurality of resonators on the surface of the piezoelectric substrate.

[Claim 9] A surface acoustic wave filter having a piezoelectric substrate and an electrode pattern that contains Al as a main component and that is formed at a surface of the piezoelectric substrate,

the surface acoustic wave filter being characterized in that

the electrode pattern has a thickness in the range of 0.03 to 0.15 of a wavelength of a surface acoustic wave excited on the piezoelectric substrate; the piezoelectric substrate has an orientation in which a $LiTaO_3$ single crystal is rotated with an angle in the range of 38 to 46° about an X axis from a Y axis toward a Z axis; and the electrode pattern includes an interdigital electrode.

[Claim 10] The surface acoustic wave filter according to claim 9, characterized in that the electrode pattern includes, on the surface of the piezoelectric substrate, a first interdigital electrode and a second interdigital electrode which are formed along a propagation path of the surface acoustic wave, the first interdigital electrode and the second interdigital electrode are connected to an input terminal and an output terminal, respectively, and the first and second interdigital electrodes further cover at least one half of the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate.

[Claim 11] The surface acoustic wave filter according to claim 10, characterized in that the first interdigital electrode has a first electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the input terminal, and a second electrode

finger group, which is constituted by a plurality of electrode fingers that are mutually connected to each other and that are interposed between the first electrode finger group, and the second interdigital electrode has a third electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the output terminal, and a fourth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to each other and that are interposed between the third electrode finger group.

[Claim 12] The surface acoustic wave filter according to claim 10 or 11, characterized in that a plurality of the first interdigital electrodes or a plurality of the second interdigital electrodes are provided, and the plurality of first interdigital electrodes and the plurality of second interdigital electrodes are alternately disposed on the surface of the piezoelectric substrate along the propagation path of the surface acoustic wave.

[Claim 13] The surface acoustic wave filter according to claim 9, characterized in that the electrode pattern includes a fist interdigital electrode and a second interdigital electrode which are formed on the surface of the piezoelectric substrate,

the first interdigital electrode has a first electrode finger group, which is constituted by a plurality of electrode fingers that are formed so as to cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to an input terminal, and a second electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to each other and that are interposed between the first electrode finger group, and

the second interdigital electrode has a third electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the second electrode finger group, and a fourth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to an output terminal and that are interposed between the second electrode finger group.

[Claim 14] The surface acoustic wave filter according to claim 13, characterized in that the electrode pattern further includes a third interdigital electrode having a fifth electrode finger group, which is constituted by a plurality of electrode fingers that are formed so as to cross the propagation path of the surface acoustic wave on

the surface of the piezoelectric substrate and that are mutually connected to the second electrode finger group, and a sixth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to ground and that are interposed between the fifth electrode finger group; and a fourth interdigital electrode having a seventh electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the fourth electrode finger group, and an eighth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to an output terminal and that are interposed between the seventh electrode finger group.

[Claim 15] The surface acoustic wave filter according to claim 11, characterized in that the electrode pattern further includes a third interdigital electrode having a fifth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to the input terminal on the surface of the piezoelectric substrate, and a sixth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to each other and that are interposed between the fifth electrode finger group, and the third

interdigital electrode is formed adjacent to the second interdigital electrode.

[Claim 16] A surface acoustic wave filter having a piezoelectric substrate and an electrode pattern that contains Al as a main component and that is formed at a surface of the piezoelectric substrate,

the surface acoustic wave filter being characterized in that the electrode pattern has a thickness in the range of 0.03 to 0.15 of a wavelength of a surface acoustic wave excited on the piezoelectric substrate; the piezoelectric substrate has an orientation in which a $LiTaO_3$ single crystal is rotated with an angle in the range of 38 to 46° about an X axis from a Y axis toward a Z axis; the electrode pattern includes, on the surface of the piezoelectric substrate, first to fifth interdigital electrodes formed along a propagation path of the surface acoustic wave; the first interdigital electrode has a first electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to an input terminal, and a second electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to each other and that are interposed between the first electrode finger group;

the second interdigital electrode has a third electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the second electrode finger group, and a fourth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to an output terminal and that are interposed between the third electrode finger group; the third interdigital electrode further has a fifth electrode finger group, which is constituted by a plurality of electrode fingers that are formed so as to cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the first electrode finger group, and a sixth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to ground and that are interposed between the fifth electrode finger group; the fourth interdigital electrode further has a seventh electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the second electrode finger group, and an eighth electrode finger group, which is constituted by a plurality of

electrode fingers that are mutually connected to an output terminal and that are interposed between the seventh electrode finger group; and

the fifth interdigital electrode further has a ninth electrode finger group, which is constituted by a plurality of electrode fingers that are formed so as cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the fourth electrode finger group, and a tenth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to ground and that are interposed between the ninth electrode finger group.

[Claim 17] A surface acoustic wave resonator having a piezoelectric substrate and an electrode pattern that contains Al as a main component and that is formed at a surface of the piezoelectric substrate,

the surface acoustic wave resonator being characterized in that the electrode pattern has a thickness in the range of 0.03 to 0.15 of a wavelength of a surface acoustic wave excited on the piezoelectric substrate; the piezoelectric substrate has an orientation in which a $LiTaO_3$ single crystal is rotated with an angle in the range of 38 to 46° about an X axis from a Y axis toward a Z axis; and the electrode pattern includes an interdigital electrode having a first

electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to a first terminal on the surface of the piezoelectric substrate, and a second electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to a second terminal and that are interposed between the first electrode finger group.

[Claim 18] A surface acoustic wave filter having a piezoelectric substrate and an electrode pattern that contains Al as a main component and that is formed at a surface of the piezoelectric substrate,

the surface acoustic wave delay line being characterized in that the electrode pattern has a thickness in the range of 0.03 to 0.15 of a wavelength of a surface acoustic wave excited on the piezoelectric substrate; the piezoelectric substrate has an orientation in which a $LiTaO_3$ single crystal is rotated with an angle in the range of 38 to 46° about an X axis from a Y axis toward a Z axis; and the electrode pattern includes an interdigital electrode.

[Claim 19] A surface acoustic wave device having a piezoelectric substrate and an electrode pattern that contains Al as a main component and that is formed at a surface of the piezoelectric substrate,

the surface acoustic wave device being characterized in that the electrode pattern has a thickness in the range of 0.04

to 0.12 of a wavelength of a surface acoustic wave excited on the piezoelectric substrate; and the piezoelectric substrate has an orientation in which a $LiNbO_3$ single crystal is rotated with an angle in the range of 66 to 74° about an X axis from a Y axis toward a Z axis.

[Claim 20] The surface acoustic wave device according to claim 20, characterized in that the piezoelectric substrate has an orientation in which the $LiNbO_3$ single crystal is rotated with an angle in the range of 68 to 72° about the X axis from the Y axis toward the Z axis.

[Claim 21] The surface acoustic wave device according to claim 19 or 20, characterized in that the electrode pattern has a thickness in the range of 0.05 to 0.10 of the wavelength of the surface acoustic wave excited on the piezoelectric substrate.

[Claim 22] The surface acoustic wave device according to one of claims 19 to 21, characterized in that the electrode pattern is made of Al.

[Claim 23] The surface acoustic wave device according to one of claims 19 to 21, characterized in that the electrode pattern is made of an Al-Cu alloy.

[Claim 24] The surface acoustic wave device according to one of claims 19 to 23, characterized in that the electrode pattern defines a ladder filter using a plurality of resonators on the surface of the piezoelectric substrate.

[Claim 25] The surface acoustic wave device according to one of claims 19 to 23, characterized in that the electrode pattern defines a resonator on the surface of the piezoelectric substrate.

[Claim 26] The surface acoustic wave device according to one of claims 19 to 23, characterized in that the electrode pattern defines a lattice filter using a plurality of resonators on the surface of the piezoelectric substrate.

[Claim 27] The surface acoustic wave device according to one of claims 19 to 23, characterized in that the electrode pattern defines an IIDT filter on the surface of the piezoelectric substrate, the IIDT filter being constituted by a plurality of input interdigital electrodes and a plurality of output interdigital electrodes.

[Claim 28] The surface acoustic wave device according to one of claims 19 to 23, characterized in that the electrode pattern defines a delay line on the surface of the piezoelectric substrate.

[Claim 29] The surface acoustic wave device according to one of claims 19 to 23, characterized in that the electrode pattern defines a multi-mode filter on the surface of the piezoelectric substrate.

[Claim 30] A surface acoustic wave filter having a piezoelectric substrate and an electrode pattern that contains Al as a main component and that is formed at a

surface of the piezoelectric substrate,

the surface acoustic wave filter being characterized in that the electrode pattern has a thickness in the range of 0.04 to 0.12 of a wavelength of a surface acoustic wave excited on the piezoelectric substrate; the piezoelectric substrate has an orientation in which a $LiNbO_3$ single crystal is rotated with an angle in the range of 66 to 74° about an X axis from a Y axis toward a Z axis; the electrode pattern includes, on a surface of the piezoelectric substrate, first to fifth interdigital electrodes formed along a propagation path of the surface acoustic wave; the first interdigital electrode has a first electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to an input terminal, and a second electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to each other and that are interposed between the first electrode finger group; the second interdigital electrode has a third electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the second electrode finger group, and a fourth electrode finger group,

which is constituted by a plurality of electrode fingers that are mutually connected to an output terminal and that are interposed between the third electrode finger group; the third interdigital electrode further has a fifth electrode finger group, which is constituted by a plurality of electrode fingers that are formed so as to cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the first electrode finger group, and a sixth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to ground and that are interposed between the fifth electrode finger group; the fourth interdigital electrode further has a seventh electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the second electrode finger group, and an eighth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to an output terminal and that are interposed between the seventh electrode finger group; and

the fifth interdigital electrode has a ninth electrode finger group, which is constituted by a plurality of electrode fingers that are formed so as cross the

propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the fourth electrode finger group, and a tenth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to ground and that are interposed between the ninth electrode finger group.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention] The present invention generally relates to surface acoustic wave devices and, more particularly, to a surface acoustic wave device having a superior passband characteristic in a high frequency band including a GH_z band.

[0002]

[Description of the Related Arts] Surface acoustic wave devices are widely used as filters or resonators for high frequency circuits in compact, lightweight wireless communication apparatuses, such as mobile telephones, that operate with very high frequency bands. Such surface acoustic wave devices are generally formed on piezoelectric single-crystal or polycrystalline substrates, which have a large electromechanical coupling coefficient k^2. Thus, the excitation efficiency of a surface acoustic wave is high. In particular, a 64° Y-X $LiNbO_3$ substrate (K. Yamanouti and K.

Shibayama, J. Appl. Phys. vol.43, no.3, March 1972, pp.856) using a $LiNbO_3$ single crystal 64° rotated Y cut plate having a surface-acoustic-wave propagation direction in the X direction or a 36° Y-X $LiTaO_3$ substrate using a $LiTaO_3$ single crystal 36° rotated Y cut plate having a surface-acoustic-wave propagation direction in the X direction is widely used as a substrate member having a small propagation loss of a surface acoustic wave in a high frequency band.

[0003] However, those cut angles become optimal when the added mass effect of electrodes formed on the piezoelectric substrate can be ignored. Thus, while the cut angles are effective in a low frequency band of several hundred MH_z or less since the wavelength of an excited surface acoustic wave is large, those cut angles are not necessarily optimal for an operation in the vicinity of a GH_z band needed for recent mobile telephones and the like since the thickness of the electrodes cannot be ignored with respect to the wavelength of the excited surface acoustic wave. For an operation in such a high frequency band, the added mass effect of the electrodes becomes more apparent.

[0004] For an operation in such a very short wavelength region, increasing the thickness of electrodes on a piezoelectric substrate and increasing the apparent electromechanical coupling coefficient makes it possible to reduce the passband width of a surface acoustic wave filter

or the capacitance ratio γ of a surface acoustic wave resonator. With such an arrangement, however, problems arise in that a bulk wave radiated from the electrodes toward the inside of the substrate increases, thereby increasing the propagation loss of the surface acoustic wave. Such a bulk wave is called an SSBW (surface skimming bulk wave) and a surface acoustic wave that involves an SSBW is called an LSAW (leaky surface acoustic wave). The propagation loss of an LSAW in a surface acoustic wave filter using a thick electrode film has been analyzed, for a 36° Y-X $LiTaO_3$ and 64° Y-X $LiNbO_3$ substrate, by Plessky et al. or Edmonson et al. (V. S. Plessky and C. S. Hartmann, Proc. 1993 IEEE Ultrasonics Symp., pp.1239-1242; P. J. Edmonson and C. K. Campbell, Proc. 1994 IEEE Ultrasonic Symp., pp.75-79).

[0005] However, in such conventional 36° Y-X $LiTaO_3$ or 64° Y-X $LiNbO_3$ surface-acoustic-wave filters using an LSAW, when the film thickness of the electrodes is small, the sound velocity of the surface acoustic wave and the sound velocity of the bulk wave come closer each other. As a result, a spurious peak due to a bulk wave appears in the passband of the filter (M. Ueda et al., Proc. 1994 IEEE Ultrasonic Symp. pp.143-146).

[0006] Fig. 21 shows spurious peaks A and B due to a bulk wave which appear in the vicinity of the passband of the

filter according to the document of Ueda et al. The filter is constructed on a 36° Y-X $LiTaO_3$ substrate and has an interdigital electrode that is made of an Al-Cu alloy having a thickness of 0.49 μm corresponding to 3% of an excited wavelength.

[0007] Referring to Fig. 21, the spurious peak B is present outside the passband formed in the vicinity of 330 MHz, while the spurious peak A is present within the passband. As a result, it is shown that ripple is generated in the passband characteristic. In a surface acoustic wave filter, the sound velocity of a surface acoustic wave depends on the added mass of electrodes, i.e., the film thickness, whereas the sound velocity of an SSBW does not depend on the film thickness of electrodes. Thus, in an operation in a high frequency band such as a GH_z band, the film thickness of the electrodes increase relative to the wavelength of an excited surface acoustic wave and the sound velocity of the surface acoustic wave decreases relative to the bulk wave. As a result, the passband of the filter shifts relative to a spurious peak, so that the passband characteristic is flattened. However, when the film thickness of the electrodes increases relative to the wavelength of a surface acoustic wave, the loss of an LSAW due to a bulk radiation increases, as described above.

[0008] Further, particularly for a surface acoustic wave

filter that operates in a very high frequency band such as a GHz band, there is a need to ensure a certain degree of film thickness to reduce the resistance of the interdigital electrodes. Such an arrangement makes it impossible to avoid the problems of an increase in the above-described loss and deterioration in a squareness ratio.

[0009] Accordingly, a general object of the present invention is to provide a novel and useful surface acoustic wave device that overcomes the conventional problems described above. A more specific object of the present invention is to provide a surface acoustic wave device that has a piezoelectric single crystal substrate cut out with a cut angle optimized with respect to the film thickness of electrodes and that has a passband set so as to avoid a spurious peak resulting from a bulk wave.

[0010]

[Means for Solving the Problems] The present invention overcomes the above described problems by any of the following claims. As recited in claim 1, in a surface acoustic wave device having a piezoelectric substrate and an electrode pattern that contains Al as a main component and that is formed at a surface of the piezoelectric substrate, the surface acoustic wave device is characterized in that the electrode pattern has a thickness in the range of 0.03 to 0.15 of a wavelength of a surface acoustic wave excited

on the piezoelectric substrate; and the piezoelectric substrate has an orientation in which a $LiTaO_3$ single crystal is rotated with an angle in the range of 38 to 46° about an X axis from a Y axis toward a Z axis. As recited in claim 2, the surface acoustic wave device according to claim 1 is characterized in that the piezoelectric substrate has an orientation in which the $LiTaO_3$ single crystal is rotated with an angle in the range of 40 to 46° about the X axis from the Y axis toward the Z axis. As recited in claim 3, the surface acoustic wave device according to claim 1 or 2 is characterized in that the electrode pattern has a thickness in the range of 0.07 to 0.15 of the wavelength of the surface acoustic wave excited on the piezoelectric substrate. As recited in claim 4, the surface acoustic wave device according to one of claims 1 to 3 is characterized in that the electrode pattern has a thickness in the range of 0.05 to 0.10 of the wavelength of the surface acoustic wave excited on the piezoelectric substrate and the piezoelectric substrate has an orientation in which the $LiTaO_3$ single crystal is rotated with an angle in the range of 40 to 44° about the X axis from the Y axis toward the Z axis. As recited in claim 5, the surface acoustic wave device according to claim 1 is characterized in that the piezoelectric substrate has an orientation in which the $LiTaO_3$ single crystal is rotated with an angle in the range

of 42° about the X axis from the Y axis toward the Z axis. As recited in claim 6, the surface acoustic wave device according to one of claims 1 to 5 is characterized in that the electrode pattern is made of Al. As recited in claim 7, the surface acoustic wave device according to one of claims 1 to 5 is characterized in that the electrode pattern is made of an Al-Cu alloy. As recited in claim 8, the surface acoustic wave device according to one of claims 1 to 7 is characterized in that the electrode pattern defines a plurality of resonators on the surface of the piezoelectric substrate. As recited in claim 9, in a surface acoustic wave filter having a piezoelectric substrate and an electrode pattern that contains Al as a main component and that is formed at a surface of the piezoelectric substrate, the surface acoustic wave filter is characterized in that the electrode pattern has a thickness in the range of 0.03 to 0.15 of a wavelength of a surface acoustic wave excited on the piezoelectric substrate; the piezoelectric substrate has an orientation in which a $LiTaO_3$ single crystal is rotated with an angle in the range of 38 to 46° about an X axis from a Y axis toward a Z axis; and the electrode pattern includes an interdigital electrode. As recited in claim 10, the surface acoustic wave filter according to claim 9 is characterized in that the electrode pattern includes, on the surface of the piezoelectric substrate, a

first interdigital electrode and a second interdigital electrode which are formed along a propagation path of the surface acoustic wave, the first interdigital electrode and the second interdigital electrode are connected to an input terminal and an output terminal, respectively, and the first and second interdigital electrodes further cover at least one half of the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate. As recited in claim 11, the surface acoustic wave filter according to claim 10 is characterized in that the first interdigital electrode has a first electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the input terminal, and a second electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to each other and that are interposed between the first electrode finger group, and the second interdigital electrode has a third electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the output terminal, and a fourth electrode finger group, which is constituted by a plurality of electrode fingers

that are mutually connected to each other and that are interposed between the third electrode finger group. As recited in claim 12, the surface acoustic wave filter according to claim 10 or 11 is characterized in that a plurality of the first interdigital electrodes or a plurality of the second interdigital electrodes are provided, and the plurality of first interdigital electrodes and the plurality of second interdigital electrodes are alternately disposed on the surface of the piezoelectric substrate along the propagation path of the surface acoustic wave. As recited in claim 13, the surface acoustic wave filter according to claim 9 is characterized in that the electrode pattern includes a fist interdigital electrode and a second interdigital electrode which are formed on the surface of the piezoelectric substrate, the first interdigital electrode has a first electrode finger group, which is constituted by a plurality of electrode fingers that are formed so as to cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to an input terminal, and a second electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to each other and that are interposed between the first electrode finger group, and the second interdigital electrode has a third electrode finger group, which is

constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the second electrode finger group, and a fourth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to an output terminal and that are interposed between the second electrode finger group. As recited in claim 14, the surface acoustic wave filter according to claim 13 is characterized in that the electrode pattern further includes a third interdigital electrode having a fifth electrode finger group, which is constituted by a plurality of electrode fingers that are formed so as to cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the second electrode finger group, and a sixth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to ground and that are interposed between the fifth electrode finger group; and a fourth interdigital electrode having a seventh electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the fourth electrode finger group, and an eighth electrode finger group,

which is constituted by a plurality of electrode fingers that are mutually connected to an output terminal and that are interposed between the seventh electrode finger group. As recited in claim 15, the surface acoustic wave filter according to claim 11 is characterized in that the electrode pattern further includes a third interdigital electrode having a fifth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to the input terminal on the surface of the piezoelectric substrate, and a sixth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to each other and that are interposed between the fifth electrode finger group, and the third interdigital electrode is formed adjacent to the second interdigital electrode. As recited in claim 16, in a surface acoustic wave filter having a piezoelectric substrate and an electrode pattern that contains Al as a main component and that is formed at a surface of the piezoelectric substrate, the surface acoustic wave filter is characterized in that the electrode pattern has a thickness in the range of 0.03 to 0.15 of a wavelength of a surface acoustic wave excited on the piezoelectric substrate; the piezoelectric substrate has an orientation in which a $LiTaO_3$ single crystal is rotated with an angle in the range of 38 to 46° about an X axis from a Y axis toward a Z axis; the

electrode pattern includes, on the surface of the piezoelectric substrate, first to fifth interdigital electrodes formed along a propagation path of the surface acoustic wave; the first interdigital electrode has a first electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to an input terminal, and a second electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to each other and that are interposed between the first electrode finger group; the second interdigital electrode has a third electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the second electrode finger group, and a fourth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to an output terminal and that are interposed between the third electrode finger group; the third interdigital electrode further has a fifth electrode finger group, which is constituted by a plurality of electrode fingers that are formed so as to cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate

and that are mutually connected to the first electrode finger group, and a sixth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to ground and that are interposed between the fifth electrode finger group; the fourth interdigital electrode further has a seventh electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the second electrode finger group, and an eighth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to an output terminal and that are interposed between the seventh electrode finger group; and the fifth interdigital electrode further has a ninth electrode finger group, which is constituted by a plurality of electrode fingers that are formed so as cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the fourth electrode finger group, and a tenth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to ground and that are interposed between the ninth electrode finger group. As recited in claim 17, in a surface acoustic wave resonator having a piezoelectric substrate and an electrode pattern that contains Al as a

main component and that is formed at a surface of the piezoelectric substrate, the surface acoustic wave resonator is characterized in that the electrode pattern has a thickness in the range of 0.03 to 0.15 of a wavelength of a surface acoustic wave excited on the piezoelectric substrate; the piezoelectric substrate has an orientation in which a $LiTaO_3$ single crystal is rotated with an angle in the range of 38 to 46° about an X axis from a Y axis toward a Z axis; and the electrode pattern includes an interdigital electrode having a first electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to a first terminal on the surface of the piezoelectric substrate, and a second electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to a second terminal and that are interposed between the first electrode finger group. As recited in claim 18, in a surface acoustic wave filter having a piezoelectric substrate and an electrode pattern that contains Al as a main component and that is formed at a surface of the piezoelectric substrate, the surface acoustic wave delay line is characterized in that the electrode pattern has a thickness in the range of 0.03 to 0.15 of a wavelength of a surface acoustic wave excited on the piezoelectric substrate; the piezoelectric substrate has an orientation in which a $LiTaO_3$ single crystal is rotated with

an angle in the range of 38 to 46° about an X axis from a Y axis toward a Z axis; and the electrode pattern includes an interdigital electrode. As recited in claim 19, in a surface acoustic wave device having a piezoelectric substrate and an electrode pattern that contains Al as a main component and that is formed at a surface of the piezoelectric substrate, the surface acoustic wave device is characterized in that the electrode pattern has a thickness in the range of 0.04 to 0.12 of a wavelength of a surface acoustic wave excited on the piezoelectric substrate; and the piezoelectric substrate has an orientation in which a $LiNbO_3$ single crystal is rotated with an angle in the range of 66 to 74° about an X axis from a Y axis toward a Z axis. As recited in claim 20, the surface acoustic wave device according to claim 20 is characterized in that the piezoelectric substrate has an orientation in which the $LiNbO_3$ single crystal is rotated with an angle in the range of 68 to 72° about the X axis from the Y axis toward the Z axis. As recited in claim 21, the surface acoustic wave device according to claim 19 or 20 is characterized in that the electrode pattern has a thickness in the range of 0.05 to 0.10 of the wavelength of the surface acoustic wave excited on the piezoelectric substrate. As recited in claim 22, the surface acoustic wave device according to one of claims 19 to 21 is characterized in that the electrode

pattern is made of Al. As recited in claim 23, the surface acoustic wave device according to one of claims 19 to 21 is characterized in that the electrode pattern is made of an Al-Cu alloy. As recited in claim 24, the surface acoustic wave device according to one of claims 19 to 23 is characterized in that the electrode pattern defines a ladder filter using a plurality of resonators on the surface of the piezoelectric substrate. As recited in claim 25, the surface acoustic wave device according to one of claims 19 to 23 is characterized in that the electrode pattern defines a resonator on the surface of the piezoelectric substrate. As recited in claim 26, the surface acoustic wave device according to one of claims 19 to 23 is characterized in that the electrode pattern defines a lattice filter using a plurality of resonators on the surface of the piezoelectric substrate. As recited in claim 27, the surface acoustic wave device according to one of claims 19 to 23 is characterized in that the electrode pattern defines an IIDT filter on the surface of the piezoelectric substrate, the IIDT filter being constituted by a plurality of input interdigital electrodes and a plurality of output interdigital electrodes. As recited in claim 28, the surface acoustic wave device according to one of claims 19 to 23 is characterized in that the electrode pattern defines a delay line on the surface of the piezoelectric substrate.

As recited in claim 29, the surface acoustic wave device according to one of claims 19 to 23, characterized in that the electrode pattern defines a multi-mode filter on the surface of the piezoelectric substrate. As recited in claim 30, in a surface acoustic wave filter having a piezoelectric substrate and an electrode pattern that contains Al as a main component and that is formed at a surface of the piezoelectric substrate, the surface acoustic wave filter is characterized in that the electrode pattern has a thickness in the range of 0.04 to 0.12 of a wavelength of a surface acoustic wave excited on the piezoelectric substrate; the piezoelectric substrate has an orientation in which a $LiNbO_3$ single crystal is rotated with an angle in the range of 66 to 74° about an X axis from a Y axis toward a Z axis; the electrode pattern includes, on a surface of the piezoelectric substrate, first to fifth interdigital electrodes formed along a propagation path of the surface acoustic wave; the first interdigital electrode has a first electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to an input terminal, and a second electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to each other and that are interposed

between the first electrode finger group; the second interdigital electrode has a third electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the second electrode finger group, and a fourth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to an output terminal and that are interposed between the third electrode finger group; the third interdigital electrode further has a fifth electrode finger group, which is constituted by a plurality of electrode fingers that are formed so as to cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the first electrode finger group, and a sixth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to ground and that are interposed between the fifth electrode finger group; the fourth interdigital electrode further has a seventh electrode finger group, which is constituted by a plurality of electrode fingers that cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the second electrode finger group, and an eighth electrode finger group, which is constituted by a

plurality of electrode fingers that are mutually connected to an output terminal and that are interposed between the seventh electrode finger group; and the fifth interdigital electrode has a ninth electrode finger group, which is constituted by a plurality of electrode fingers that are formed so as cross the propagation path of the surface acoustic wave on the surface of the piezoelectric substrate and that are mutually connected to the fourth electrode finger group, and a tenth electrode finger group, which is constituted by a plurality of electrode fingers that are mutually connected to ground and that are interposed between the ninth electrode finger group. The present invention will be described below with reference to Figs. 1 to 3.

[0011] Fig. 1 is a view for illustrating the cut-out angle of a piezoelectric crystal substrate. Fig. 1 shows a state in which a $LiTaO_3$ piezoelectric single crystal or the like, which has crystal axes X, Y, and Z, has been cut out with an angle tiled by a rotation angle θ around the crystal axis X from the Y axis toward the Z axis. Such a piezoelectric crystal substrate is called a θ rotated Y-X substrate.

[0012] Fig. 2 shows the insertion loss of a resonator formed on a $LiTaO_3$ single crystal θ rotated Y-X substrate versus various cut-out angles or rotation angles θ. As described above, conventionally, when a surface acoustic wave device is formed on a $LiTaO_3$ substrate, a 36° Y-X

substrate has been commonly used, and, when a surface acoustic wave device is formed on a $LiNbO_3$ substrate, a 64° Y-X substrate has been commonly used. This is because, with those rotation angles, the propagation loss with respect to a relatively-long wavelength surface acoustic wave, in which the added mass effect of electrodes formed on a substrate surface can be ignored, becomes minimal. A reference is made of, for example, Nakamura, et al, Shingaku Gihou US77-42.

[0013] In Fig. 2, the curve represented by the black dots is obtained by calculation of the propagation loss of an LSAW when virtual electrodes having a thickness of zero are uniformly formed on a surface of a $LiTaO_3$ 36° Y-X substrate. It can be seen that the propagation loss is minimal at a rotation angle θ of 36°. For this calculation, crystal constants reported by Kovacs et al. were used (G. Kovacs, et al., Proc. 1990 IEEE Ultrasonic Symp. pp.435-438).

[0014] However, in a short wavelength region such as a GH_z band, as described above, the thickness of the electrodes cannot be ignored with respect to the wavelength of an excited surface acoustic wave, and the added mass effect of the electrodes becomes more apparent. The inventors of the present invention have discovered that the added mass effect causes the propagation loss characteristic shown in Fig. 2 to change in the direction of the arrow and causes the

rotation angle θ that provides a minimum propagation loss to shift toward a larger angle as indicated by the white dots in Fig. 2. In Fig. 2, however, the curve represented by the white dots shows a case in which Al electrodes are uniformly formed on a piezoelectric substrate and further the film thickness of the electrodes is of 10% of the wavelength of an excited surface acoustic wave.

[0015] In addition, Fig. 3 shows the relationship between the propagation loss and the rotation angle θ when Al grating electrodes are formed on a $LiTaO_3$ substrate. In Fig. 3, however, the broken line indicates a case in which the film thickness of the electrodes is zero and the solid line indicates a case in which the film thickness of the electrodes is of 10% of the wavelength of an excited surface acoustic wave. Clearly, as a result of the formation of the grating having a film thickness that is finite with respect to the wavelength of an excited surface acoustic wave on the substrate, the rotation angle at which the propagation loss becomes minimal shifts toward a larger angle.

[0016] Thus, setting the rotation angle θ of a $LiTaO_3$ single crystal substrate to be larger than the conventional angle 36° can provide a surface acoustic wave device having a high Q and having reduced attenuation of a surface acoustic wave in a GH_z band. In conjunction with the added mass effect of the electrodes at such high frequencies, the position of the

passband of the filter shown in Fig. 21 shifts toward lower frequencies relative to the spurious peaks A and B. Thus, a surface acoustic wave device formed on a $LiTaO_3$ substrate having such a large rotation angle allows the spurious peaks A and B to be displaced from the passband of the filter. As described above, the spurious peaks A and B are attributed to a bulk wave and are not affected by the added mass of electrodes.

[0017] Further, according to the present invention, it has been discovered that the squareness ratio of the passband characteristic also changes in accordance with the rotation angle θ and, particularly in a GH_z band, a $LiTaO_3$ substrate that has been cut out with a larger angle than a conventionally-used rotation angle θ yields a superior passband width and a squareness ratio. Figs. 4 and 5 show the frequency temperature characteristic and the minimum insertion-loss temperature characteristic, respectively, of a surface acoustic wave filter formed on a $LiTaO_3$ substrate. A configuration described below and shown in Fig. 7 was used for the surface acoustic wave filter, and the surface acoustic wave filter was formed on a $LiTaO_3$ substrate with a varied rotation angle θ such that the film thickness of the electrodes becomes 10% of the wavelength of an excited surface acoustic wave.

[0018] As is seen from Fig. 4, the filter displays

substantially the same temperature characteristic when the rotation angle, i.e., the cut angle θ of the substrate is any of 36° Y, 40° Y, 42° Y, and 44° Y. Various changes in the center frequency appear to have resulted from a difference in sound velocity in the substrate and a variation in a sample fabrication condition.

[0019] As is seen from Fig. 5, when the rotation angle θ of the $LiTaO_3$ substrate is set in the range of 40° Y to 44° Y, the loss decreases in at least a typical temperature region, that is, in the range of -35°C to 85°C, compared to a case in which the rotation angle θ is set to the conventional angle 36° Y. In particular, it can be seen that, when the rotation angle θ is set in the range of 40° Y to 42° Y, the fluctuation width of the minimum insertion loss also decreases.

[0020] Further, Fig. 6 shows the insertion loss of a resonator formed on a $LiNbO_3$ single crystal θ rotated Y-X substrate versus various cut-out angles or rotation angles θ. In Fig. 6, the curve represented by the broken line is obtained by calculation of the propagation loss of an LSAW when virtual electrodes having a film thickness of zero are uniformly formed on a surface of a 64° $LiNbO_3$ Y-X substrate. It can be seen that the propagation loss is minimal at a rotation angle θ of 64°. For this calculation, crystal constants reported by Warner et al. were used (J. Acoust.

Soc. Amer., 42, 1967, pp.1223-1231).

[0021] However, in a short wavelength region such as a GH_z band, as described above, the thickness of the electrodes cannot be ignored with respect to the wavelength of an excited surface acoustic wave, and the added mass effect of the electrodes becomes more apparent. The inventors of the present invention have discovered that the added mass effect causes the propagation loss characteristic shown in Fig. 6 to change in the direction of the arrow and causes the rotation angle θ that provides a minimum propagation loss to shift toward a larger angle as indicated by the solid lines in Figs. 2 and 3. In Fig. 2, however, the curve represented by the solid line indicates a case in which the film thickness of the electrodes is of 3% of the wavelength of an excited surface acoustic wave.

[0022] Thus, setting the rotation angle θ of a $LiNbO_3$ single crystal substrate to be larger than the conventional angle 64° can provide a surface acoustic wave device having a high Q and having reduced attenuation of a surface acoustic wave in a GH_z band.

[0023]

[Embodiments] The present invention will be described below in detail in conjunction with preferred embodiments thereof. Fig. 7(A) is a plan view showing the configuration of a ladder surface-acoustic-wave filter according to a first

embodiment of the present invention, and Fig. 7(B) is an equivalent circuit diagram thereof.

[0024] Referring to Fig. 7(A), a surface acoustic wave filter is formed on a $LiTaO_3$ or $LiNbO_3$ single crystal rotated Y plate. The surface acoustic wave filter includes a first interdigital electrode R_1 having an input-side electrode connected to an input terminal IN, a second interdigital electrode R_1' having an input-side electrode connected to an output-side electrode of the interdigital electrode R_1 and having an output-side electrode connected to an output terminal OUT, a third interdigital electrode R_2 having an input-side electrode connected to the input-side electrode of the interdigital electrode R_1' and having an output-side electrode connected to ground, a fourth interdigital electrode R_2' having an input-side electrode connected to the output-side electrode of the interdigital electrode R_1 and having an output-side electrode connected to ground, and a fourth interdigital electrode R_2'' having an input-side electrode connected to the output-side electrode of the interdigital electrode R_1' and having an output-side electrode connected to ground.

[0025] In each of the interdigital electrodes R_1, R_1', R_2, R_2', and R_2'', an input-side electrode i commonly includes a first group of electrode fingers extending parallel to each other in a first direction that crosses the path of a

surface acoustic wave propagating in the X-axis direction. An output-side electrode o commonly includes a second group of electrode fingers extending parallel to each other in a second direction that is opposite to the first direction. The first group of electrode fingers and the second group of electrode fingers are alternately disposed. Further, each of the interdigital electrodes R_1, R_1', R_2, R_2', and R_2'' has reflectors R_1 at two opposite sides along the X-axis direction. The reflectors R_1 have a configuration in which a plurality of parallel electrode fingers are short-circuited at two opposite ends. In this embodiment, the interdigital electrodes R_1, R_1', R_2, R_2', and R_2'' are made of an Al-1%Cu alloy and are formed to have a thickness of about 0.4 µm corresponding to 10% of the passband wavelength of the filter.

[0026] Fig. 7(B) is an equivalent circuit diagram of the filter shown in Fig. 6(A). Referring to Fig. 7(B), the interdigital electrodes R_1 and R_1' are connected in series and further the interdigital electrodes R_2, R_2', and R_2'' are connected in parallel. Fig. 8 shows a minimum insertion loss empirically obtained for the surface acoustic wave filter shown in Figs. 7(A) and 7(B) versus various cut angles θ of the $LiTaO_3$ single crystal substrate 11. The minimum insertion loss includes both effects of the propagation loss of the surface acoustic wave and the

matching loss of the filter, but the cut angle θ of the substrate does not substantially contribute to the matching loss.

[0027] Referring to Fig. 8, it is shown that the minimum insertion loss decreases as the cut angle of the substrate increases and the minimum insertion loss reaches a minimum at a cut angle of about 42°. When the cut angle exceeds 42°, the minimum insertion loss increases again. Thus, in terms of the insertion loss of the filter, setting the cut angle of the $LiTaO_3$ substrate 11 to be in the range of 38° to 46° allows the filter insertion loss to be suppressed to 1.6 dB or less.

[0028] According to the present invention, it has been discovered that the cut angle of a $LiTaO_3$ single crystal substrate also affects the squareness ratio of the surface acoustic wave filter. Fig. 9(A) illustrates the definition of the squareness ratio. Referring to Fig. 9(A), the squareness ratio is given by BW_1/BW_2, where BW_2 indicates a bandwidth that provides an attenuation of 1.5 dB for the minimum insertion loss of the passband and BW_1 indicates a bandwidth that provides an attenuation of 20 dB. As the squareness ratio increases, the filter becomes broader, thus deteriorating the selectivity and also reducing the passband width. It is, therefore, desirable to design the surface acoustic wave filter such that the squareness ratio

approaches 1 as close as possible.

[0029] Fig. 9(B) shows the squareness ratio empirically obtained for the surface acoustic wave filter shown in Figs. 7(A) and 7(B), as a function of the cut angle θ of the piezoelectric substrate 11. As can be seen from Fig. 9(B), as the cut angle θ increases, the squareness ratio approaches 1, and reaches a minimum value 1.47 at the cut angle θ=42°. On the other hand, when the cut angle increases to exceed 42°, the squareness ratio also increases, thus deteriorating the selectivity of the filter. In the surface acoustic wave filter of the present invention, it is desirable that the minimum insertion loss is 1.6 dB or less and the squareness ratio is 1.55 or less. Thus, it can be seen from Fig. 9(B) that it is preferable that the cut angle θ of the $LiTaO_3$ substrate be in the range of 40 to 46°, and, more particularly, in the range of 40 to 44°. In particular, setting the cut angle θ to be 42° can minimize the minimum insertion loss and also minimize the squareness ratio.

[0030] Fig. 10 shows passband characteristics empirically obtained for the surface acoustic wave filter of Figs. 7(A) and 7(B). In Fig. 10, the solid line indicates a case in which a $LiTaO_3$ 42° Y-X substrate is used for the substrate 11, while the dashed-dotted line indicates a case in which a $LiTaO_3$ 36° Y-X substrate is used for the substrate 11.

[0031] Referring to Fig. 10, the passband characteristic is

characterized by having a center frequency of 880 MH_z and a flat passband of about 40 MH_z. It can be seen that, while displaying a rapid increase in the attenuation outside the passband, the filter using the 42° Y-X substrate exhibits a steep characteristic, i.e., an improved squareness ratio, compared to the filter using the conventional 36° Y-X substrate. Further, in Fig. 10, spurious peaks A and B resulting from an SSBW are observed outside the passband of the filter.

[0032] Fig. 11 shows the result of calculation of the electromechanical coupling coefficient k^2 when electrodes having a thickness of 7% relative to the wavelength of the surface acoustic wave were formed on a surface of a $LiTaO_3$ rotated Y-X plate substrate, with respect to various cut angles θ. For the calculation, the crystal constants reported by Kovacs et al. (previously mentioned) were used.

[0033] Referring to Fig. 11, it is shown that the electromechanical coupling coefficient k^2 displays a decreasing tendency as the cut angle increases. As is well known, the electromechanical coupling coefficient k^2 is a quantity representing the rate of energy accumulated in a piezoelectric crystal due to the piezoelectric effect. When the value is small, problems arise, such as a reduction in the passband width and the generation of ripple in the passband. It can be seen from Fig. 11 that it is also

preferable the cut angle θ be set to 46° or less.

[0034] Fig. 12 shows the result of calculation of the propagation loss in the filter shown in Figs. 7(A) and 7(B) when the thickness of the interdigital electrodes formed on the $LiTaO_3$ rotated-Y X-propagation substrate 11 with a varied cut angle was changed. In the same manner as the previous calculation, for the calculation for Fig. 12, the crystal constants of Kovacs et al. were used.

[0035] As is seen from Fig. 12, when the cut angle is 38° or less, the loss increases exponentially and monotonously as the electrode thickness increases. However, when the cut angle exceeds 40°, the loss begins to decrease as the electrode thickness increases and a minimum point appears in the characteristic curve. After passing the minimum point, the loss begins to increase again. In particular, when the cut angle of the substrate 11 is set to be in the range of 40° to 46° which are preferable angles described above, such a minimum point appears where the electrode thickness relative to the wavelength is 3% or more. In other words, for the filter of the present embodiment, it is preferable that the electrodes be formed such that the thickness defined by the wavelength is 3% or more. On the other hand, an excessive electrode thickness makes it difficult to pattern the electrodes by etching and causes the sound velocity in the substrate to change more responsive to the

electrode film thickness. Thus, it is preferable that the electrodes be formed to have a thickness of 15% or less relative to the wavelength. Fig. 12 shows that, for electrodes using an Al or Al-1%Cu alloy, an electrode thickness that exceeds 15% causes the propagation loss to increase sharply with any cut angle. This indicates that the radiation of bulk waves becomes predominant. In particular, it is preferable that the electrode thickness is in the range of 0.07 to 0.15 for a cut angle of 40 to 46° and the electrode thickness is in the range of 0.05 to 0.10 for a cut angle of 40 to 44°.

[0036] Fig. 13 shows the result of calculation of the propagation loss when the thickness of the interdigital electrodes formed on the substrate 11, for which a $LiNbO_3$ rotated Y-X plate with a varied cut angle is used, in the filter shown in Figs. 7(A) and 7(B) was changed relative to the wavelength of an excited surface acoustic wave. For the calculation for Fig. 13, the above-noted crystal constants of Warner et al. were used.

[0037] As is seen from Fig. 13, as the electrode film thickness increases, the propagation loss temporarily reaches a minimum value and then begins to increase exponentially. With a rotation angle of 64° or less, which has conventionally been used, the propagation loss reaches a minimum where the electrode film thickness relative to the

wavelength is 3.5% or less. In this case, however, the electrode film thickness further increases, and, when it exceeds 4% of the wavelength of the excited surface acoustic wave, the propagation loss increases sharply. On the other hand, when the cut angle of the substrate is set to 66° or more, the propagation loss reaches a minimum where the electrode film thickness is 4% or more of the excited surface acoustic wave, that is, under a condition that the added mass effect of the electrodes is prominent. In other words, under a condition that the electrode film thickness cannot be ignored with respect to the wavelength of the excited surface acoustic wave, such as a condition that the electrode film thickness defined by the wavelength is 4% or more, it is desirable to set the cut angle of the $LiNbO_3$ substrate to be 66° or more. On the other hand, an excessive electrode thickness makes it difficult to pattern the electrodes by etching and causes the sound velocity in the substrate to change more responsive to the electrode film thickness. Thus, it is preferable that the electrodes be formed to have a thickness of 12% or less relative to the wavelength. Correspondingly, it is preferable that the cut angle of the $LiNbO_3$ substrate be set in the range of 66° to 74°.

[0038] While the electrodes are composed of Al-1%Cu in the above embodiment, Use of pure Al can also satisfy similar

relationships. When other electrode material, for example, Au, is used to form the electrodes on a $LiTaO_3$ substrate, the electrode thickness is preferably set in the range of 0.4 to 2.1% of the wavelength. Further, when Au is used to form the electrodes on a $LiNbO_3$ substrate, the electrode thickness is preferably set in the range of 0.5 to 1.7% of the wavelength. Also, when Cu is used to form the electrodes on a $LiTaO_3$ substrate, the electrode thickness is preferably set in the range of 0.9 to 4.5% of the wavelength. Further, when Cu is used to form the electrodes on a $LiNbO_3$ substrate, the electrode thickness is preferably set in the range of 1.2 to 3.6% of the wavelength.

[0039] Fig. 14(A) shows a modification of the surface acoustic wave filter shown in Fig. 7(A), and Fig. 14(B) is an equivalent circuit diagram thereof. In Figs. 14(A) and 14(B), the portions previously described are denoted with the same reference characters, and the descriptions thereof are omitted. Referring to Fig. 14(A), the surface acoustic wave filter is formed on a $LiTaO_3$ or $LiNbO_3$ single crystal rotated Y plate, as in the embodiment shown in Fig. 7(A). The surface acoustic wave filter includes a first interdigital electrode R_1 having an input-side electrode connected to an input terminal IN, a second interdigital electrode R_1' having an input-side electrode connected to an output-side electrode of the interdigital electrode R_1 and

having an output-side electrode connected to an output terminal OUT, a third interdigital electrode R_2' having an input-side electrode connected to the output-side electrode of the interdigital electrode R_1 and having an output-side electrode connected to ground, and a fourth interdigital electrode R_2 having an input-side electrode connected to the output-side electrode of the interdigital electrode R_1' and having an output-side electrode connected to ground.

[0040] Referring to Fig. 14(B), the interdigital electrodes R_1 and R_1' are connected in series and further the interdigital electrodes R_2 and R_2' are connected in parallel. Each of the interdigital electrodes R_1, R_1', R_2, and R_2' defines a transducer, and the interdigital electrode R_1' has about one half the capacity of the interdigital electrode R_1. The interdigital electrode R_2', on the other hand, has about twice the capacity of the interdigital electrode R_2.

[0041] In a surface acoustic wave filter having such a configuration as well, setting the rotation angle θ to be in the range of 38° to 46°, more preferably, in the range of 40° to 46°, and most preferably, about 42° with a $LiTaO_3$ substrate or setting the rotation angle θ to be in the range of 66° to 74° and, more preferably, about 68° with a $LiNbO_3$ substrate can minimize the propagation loss even in a frequency band, for example, in which the added mass effect of the electrodes on the substrate becomes prominent.

[0042] The present invention is not limited to the above-described ladder surface-acoustic-wave filter and is also applicable to other types of surface acoustic wave filter, resonator, or propagation delay line. For example, the filter shown in Figs. 14(A) and 14(B) can be modified such that a lattice filter shown in Fig. 15 is formed.

[0043] Fig. 16 shows a surface acoustic wave filter 20 having an IIDT (interdigital-interdigital transducer) structure according to a second embodiment of the present invention. Referring to Fig. 16, the IIDT filter 20 is formed on the above-noted rotated Y-X $LiTaO_3$ substrate 11 having a cut angle of 38 to 46° or the rotated Y-X $LiNbO_3$ substrate 11 having a cut angle of 68 to 72°. When the $LiTaO_3$ substrate is used, interdigital electrodes having a thickness in the range of 3 to 15% of an excited surface acoustic wave are formed, and, when the $LiNbO_3$ substrate is used, interdigital electrodes having a thickness in the range of 4 to 12% of an excited surface acoustic wave are formed. In this embodiment as well, an LSAW is excited as a surface acoustic wave, and the excited surface acoustic wave propagates in the X axis direction.

[0044] The interdigital electrodes are constituted by input-side interdigital electrodes Rin and output-side interdigital electrodes Rout, which are alternately disposed along the propagation path of the surface acoustic wave.

Each input-side interdigital electrodes Rin has a first group of parallel electrode fingers, which are mutually connected to an input terminal 21 and which cross the propagation path of the surface acoustic wave, and a second group of electrode fingers, which are mutually connected and which are interposed between the first group of electrode fingers. Similarly, each output-side interdigital electrodes Rout has a second group of parallel electrode fingers, which are mutually connected to an output terminal 22 and which cross the propagation path of the surface acoustic wave, and a second group of electrode fingers, which are mutually connected and which are interposed between the first group of electrode fingers. The first group of electrode fingers of the output-side interdigital electrode Rout extends in an opposite direction to that of the first group of the electrode fingers of the input-side interdigital electrode Rin. Thus, the interdigital electrodes cover at least one half of the propagation path of the surface acoustic wave. In addition, a pair of reflectors Rf are provided at two opposite ends of the row of the interdigital electrodes Rin and Rout in the X direction.

[0045] With such an arrangement, as in the device shown in Figs. 7(A) and 7(B), optimizing the cut angle and the electrode film thickness of a LiTaO3 single crystal rotated

Y-X plate can provide a filter having a minimum loss, an improved squareness ratio, and a wide passband.

[0046] Fig. 17 shows the configuration of a surface acoustic wave filter 30 according to a third embodiment of the present invention. Referring to Fig. 17, the surface acoustic wave filter 30 is formed on a substrate using the above-noted rotated Y-X $LiTaO_3$ plate having a cut angle of 38 to 46° or the rotated Y-X $LiNbO_3$ plate having a cut angle of 66 to 74°. When the $LiTaO_3$ substrate is used, interdigital electrodes having a thickness in the range of 3 to 15% of the wavelength are formed. When the $LiNbO_3$ substrate is used, the thickness of the interdigital electrodes is set to be in the range of 4 to 12% of the wavelength. In this embodiment as well, an LSAW is excited as a surface acoustic wave, and the excited surface acoustic wave propagates in the X axis direction.

[0047] The surface acoustic wave filter 30 has a configuration in which a pair of interdigital electrodes having similar configurations to those of the input-side interdigital electrodes R_{in} and the output-side interdigital electrodes R_{out} of the device shown in Fig. 11 are disposed adjacent to each other. Further, a pair of reflectors R1 are disposed outside the interdigital electrodes. With this arrangement, as in the device shown in Figs. 7(A) and 7(B), optimizing the cut angle of the substrate and the film

thickness of the electrodes can provide a filter having a minimum loss, an improved squareness ratio, and a wide passband characteristic.

[0048] Fig. 18 shows the configuration of a surface acoustic wave filter 40 according to a fourth embodiment of the present invention. Referring to Fig. 18, the surface acoustic wave resonator 40 is formed on the substrate 11 using the above-noted rotated Y-X $LiTaO_3$ plate having a cut angle of 38 to 46° or the rotated Y-X $LiNbO_3$ plate having a cut angle of 66 to 74°. When the $LiTaO_3$ substrate is used, interdigital electrodes having a thickness in the range of 3 to 15% of the wavelength are formed. On the other hand, when the $LiNbO_3$ substrate is used, interdigital electrodes having a thickness in the range of 4 to 12% of the wavelength are formed. In this embodiment as well, an LSAW is excited as a surface acoustic wave, and the excited surface acoustic wave propagates in the X axis direction.

[0049] The surface acoustic wave filter 40 has an interdigital electrode R_{out} having a similar configuration to that of the output-side interdigital electrodes of the device in Fig. 16 and interdigital electrodes R_{in} having a similar configuration to that of the output-side interdigital electrodes of the device in Fig. 16. The interdigital electrodes R_{in} are disposed at two opposite sides of the interdigital electrode R_{out}, and further,

outside thereof, a pair of reflectors Rl are disposed. In this case, the interdigital electrodes R_{in} are connected to an input terminal 41, while the interdigital electrode R_{out} is connected to an output terminal 42.

[0050] With this configuration, as in the device shown in Figs. 7(A) and 7(B), optimizing the cut angle of the substrate and the film thickness of the electrodes can provide a resonator having a minimum loss and a high Q factor. Fig. 19 shows the configuration of a one-port surface-acoustic-wave resonator 50 according to a fifth embodiment of the present invention.

[0051] Referring to Fig. 19, The surface acoustic wave resonator 50 is formed on the substrate 11 using the above-noted rotated Y-X $LiTaO_3$ plate having a cut angle of 38 to 46° or the rotated Y-X $LiNbO_3$ plate having a cut angle of 66 to 74°. When the $LiTaO_3$ substrate is used, interdigital electrodes having a thickness in the range of 3 to 15% of the wavelength are formed on the substrate 11. On the other hand, when the $LiNbO_3$ substrate is used, interdigital electrodes having a thickness in the range of 4 to 12% of the wavelength are formed on the substrate 11. In this embodiment as well, an LSAW is excited as a surface acoustic wave, and the excited surface acoustic wave propagates in the X axis direction.

[0052] The surface acoustic wave resonator 50 includes a

single interdigital electrode R formed on the substrate and a pair of reflectors Rl disposed at two opposite sides of interdigital electrode R. One electrode at one side which is included in the interdigital electrode R is connected to a first terminal 51 and the electrode at the other side is connected to a second terminal 52.

[0053] With this arrangement, as in the device shown in Figs. 7(A) and 7(B), optimizing the cut angle of the substrate and the film thickness of the electrodes can provide a resonator having a minimum loss and a high Q factor. Fig. 20 shows the configuration of a two-port surface-acoustic-wave filter according to a sixth embodiment of the present invention.

[0054] Referring to Fig. 20, a surface acoustic wave resonator 60 is formed on the substrate 11 using the above-noted rotated Y-X $LiTaO_3$ plate having a cut angle of 38 to 46° or the rotated Y-X $LiNbO_3$ plate having a cut angle of 66 to 74°. When the $LiTaO_3$ substrate is used, interdigital electrodes having a thickness in the range of 3 to 15% of the wavelength are formed on the substrate 11. On the other hand, when the $LiNbO_3$ substrate is used, interdigital electrodes having a thickness in the range of 4 to 12% of the wavelength are formed on the substrate 11. In this embodiment as well, an LSAW is excited as a surface acoustic wave, and the excited surface acoustic wave propagates in

the X axis direction. The surface acoustic wave filter 60 has a pair of interdigital electrodes R_1 and R_2 that are connected to an input terminal 61 and an output terminal 62, respectively, and that have configurations similar to those of the input-side interdigital electrode R_{in} and the output-side interdigital electrode R_{out} of the device show in Fig. 16. Further, a pair of reflectors Rl are disposed outside the interdigital electrodes R_1 and R_2. The resonator 60 is driven in response to application of a voltage between the first terminal 61, which is connected to a first electrode finger group of the interdigital electrode R_1, and the second terminal 62, which is connected to a first electrode finger group of the interdigital electrode R_2. A second electrode finger group of the interdigital electrode R_1 and a second electrode finger group of the interdigital electrode R_2 are connected to ground.

[0055] With this arrangement, as in the device shown in Figs. 7(A) and 7(B), optimizing the cut angle of the substrate and the film thickness of the electrodes can provide a resonator having a minimum loss and a high Q factor. Additionally, the surface acoustic wave devices of the present invention are not limited to the above-described surface acoustic wave filters and the surface acoustic wave resonators, and are also useful for surface-acoustic-wave delay lines or waveguides which have similar configurations.

[0056]

[Advantages] According to the features of the present invention recited in claims 1 to 5, optimizing the cut angle of a $LiTaO_3$ substrate with respect to the added mass of electrodes formed on a surface of the substrate can provide a surface acoustic wave device having a minimum loss, a wide bandwidth, and a superior squareness ratio.

[0057] According to the features of the present invention recited in claims 6 and 7, the electrodes formed on the surface of the $LiTaO_3$ substrate is formed of Al-based material. This can facilitate patterning of the electrodes with less expensive material. According to the features of the present invention recited in claims 8 to 18, optimizing the cut angle of the $LiTaO_3$ substrate with respect to the added mass of the electrodes formed on the surface of the substrate can provide a surface acoustic wave filter or a resonator which has various configurations and which has a minimum loss, a wide bandwidth, and a superior squareness ratio.

[0058] According to the features of the present invention recited in claims 19 to 21, optimizing the cut angle of a $LiNbO_3$ substrate with respect to the added mass of the electrodes formed on the surface of the substrate can provide a surface acoustic wave device having a minimum loss, a wide bandwidth, and a superior squareness ratio.

According to the features of the present invention recited in claims 22 and 23, the electrodes are formed of an Al-based material on a substrate of a $LiNbO_3$ substrate. This can facilitate patterning of the electrodes with less expensive material.

[0059] According to the features of the present invention recited in claims 24 to 30, optimizing the cut angle of the $LiNbO_3$ substrate with respect to the added mass of the electrodes formed on a substrate surface can configure various surface acoustic wave devices having a minimum loss, a wide bandwidth, and a superior squareness ratio.

[Brief Description of the Drawings]

[Fig. 1] Fig. 1 is a view for illustrating the cut-out angle of a piezoelectric single crystal substrate.

[Fig. 2] Fig. 2 is a graph for illustrating a principle of the present invention.

[Fig. 3] Fig. 3 is another graph for illustrating the principle of the present invention.

[Fig. 4] Fig. 4 is a graph showing the temperature dependence of a formed surface acoustic wave filter, particularly, the temperature dependence of the center frequency with respect to a $LiTaO_3$ substrate with a varied cut angle.

[Fig. 5] Fig. 5 is a graph showing the temperature dependence of a formed surface acoustic wave filter,

particularly, the temperature dependence of a minimum insertion loss with respect to a $LiTaO_3$ substrate with various cut angles.

[Fig. 6] Fig. 6 is a graph showing the propagation loss of a surface acoustic wave filter formed on a $LiNbO_3$ substrate as a function of the cut angle of the substrate.

[Fig. 7] Figs. 7(A) and 7(B) are a view for illustrating a surface acoustic wave filter according to a first embodiment of the present invention and an equivalent circuit diagram thereof, respectively.

[Fig. 8] Fig. 8 is a graph for illustrating the minimum insertion loss of the surface acoustic wave filter shown in Fig. 7 versus the cut angle of the piezoelectric substrate included in the filter.

[Fig. 9] Fig. 9(A) is a graph for illustrating the definition of a squareness ratio in a filter passband characteristic and Fig. 9(B) is a graph for illustrating the squareness ratio versus the substrate cut angle.

[Fig. 10] Fig. 10 is a graph for illustrating passband characteristics of the filter shown in Figs. 7(A) and 7(B).

[Fig. 11] Fig. 11 is a graph illustrating the substrate cut angle versus an electromechanical coupling coefficient when a $LiTaO_3$ substrate is used for the filter shown in Figs. 7(A) and 7(B).

[Fig. 12] Fig. 12 is a graph for illustrating the effect

of an electrode film thickness for a propagation loss, with respect to various substrate cut-angles, when a $LiTaO_3$ substrate is used for the filter shown in Figs. 7(A) and 7(B).

[Fig. 13] Fig. 13 is a graph illustrating the effect of an electrode film thickness for a propagation loss, with respect to various substrate cut-angles, when a $LiNbO_3$ substrate is used for the filter shown in Figs. 7(A) and 7(B).

[Fig. 14] Figs. 14(A) and 14(B) are a view of the configuration of a surface acoustic wave filter according to a modification of the first embodiment of the present invention and an equivalent circuit of the modification, respectively.

[Fig. 15] Fig. 15 is an equivalent circuit diagram of the surface acoustic wave filter according to the modification shown in Fig. 14.

[Fig. 16] Fig. 16 is a view showing the configuration of a surface acoustic wave filter according to a second embodiment of the present invention.

[Fig. 17] Fig. 17 is a view showing the configuration of a surface acoustic wave filter according to a third embodiment of the present invention.

[Fig. 18] Fig. 18 is a view showing the configuration of a surface acoustic wave filter according to a fourth

embodiment of the present invention.

[Fig. 19] Fig. 19 is a view showing the configuration of a one-port surface acoustic wave resonator according to a fifth embodiment of the present invention.

[Fig. 20] Fig. 20 is a view showing the configuration of a two-port surface acoustic wave resonator according to a sixth embodiment of the present invention.

[Fig. 21] Fig. 21 is a graph showing an example of a passband characteristic of a known surface acoustic wave device.

[Description of Reference Numerals]

10, 20, 30, 40, 50, 60: surface acoustic wave filter

11: piezoelectric substrate

21, 31, 41, 51, 61: input terminal

22, 32, 42, 52, 62: output terminal

R_1, R_1', R_2, R_2': interdigital electrode

Rl: reflector

[FIG. 1]

A VIEW FOR ILLUSTRATING THE CUT-OUT ANGLE OF A PIEZOELECTRIC SINGLE CRYSTAL SUBSTRATE

[FIG. 2]

A GRAPH FOR ILLUSTRATING A PRINCIPLE OF THE PRESENT INVENTION

PROPAGATION LOSS (DB/WAVELENGTH)

UNIFORM ELECTRODE (FILM THICKNESS = 0)

UNIFORM ELECTRODE (FILM THICKNESS = 0.1)

ROTATION ANGLE (DEGREE)

[FIG. 3]

ANOTHER GRAPH FOR ILLUSTRATING THE PRINCIPLE OF THE PRESENT INVENTION

PROPAGATION LOSS (DB/WAVELENGTH)

ELECTRODE FILM THICKNESS 0%

ELECTRODE FILM THICKNESS 10%

ROTATION ANGLE (θ)

PROPAGATION LOSS WHEN A GRATING ELECTRODE IS FORMED ON A $LiTaO_3$ SUBSTRATE

[FIG. 4]

A GRAPH SHOWING THE TEMPERATURE DEPENDENCE OF A FORMED SURFACE ACOUSTIC WAVE FILTER, PARTICULARLY, THE TEMPERATURE DEPENDENCE OF THE CENTER FREQUENCY WITH RESPECT TO A $LITAO_3$ SUBSTRATE WITH A VARIED CUT ANGLE

CENTER FREQUENCY (MHZ)

TEMPERATURE (°C)

[FIG. 5]

A GRAPH SHOWING THE TEMPERATURE DEPENDENCE OF A FORMED SURFACE ACOUSTIC WAVE FILTER, PARTICULARLY, THE TEMPERATURE DEPENDENCE OF A MINIMUM INSERTION LOSS WITH RESPECT TO A $LITAO_3$ SUBSTRATE WITH A VARIED CUT ANGLE

MINIMUM INSERTION LOSS (DB)

TEMPERATURE (°C)

[FIG. 6]

A GRAPH SHOWING THE PROPAGATION LOSS OF A SURFACE ACOUSTIC WAVE FILTER FORMED ON A $LINBO_3$ SUBSTRATE, AS A FUNCTION OF THE CUT ANGLE OF THE SUBSTRATE

PROPAGATION LOSS [DB/λ]

ROTATION ANGLE (DEGREE)

[FIG. 7]

FIG. 7(A) IS A VIEW FOR ILLUSTRATING A SURFACE ACOUSTIC WAVE FILTER ACCORDING TO A FIRST EMBODIMENT OF THE PRESENT INVENTION AND FIG. 7(B) IS AN EQUIVALENT CIRCUIT DIAGRAM THEREOF

[FIG. 8]

A GRAPH FOR ILLUSTRATING THE MINIMUM INSERTION LOSS OF THE SURFACE ACOUSTIC WAVE FILTER SHOWN IN FIG. 7 VERSUS THE CUT ANGLE OF THE PIEZOELECTRIC SUBSTRATE INCLUDED IN THE FILTER

MINIMUM INSERTION LOSS (DB)

ROTATION ANGLE (CUT ANGLE) θ (°)

[FIG. 9]

FIG. 9(A) IS A GRAPH FOR ILLUSTRATING THE DEFINITION OF A SQUARENESS RATIO IN A FILTER PASSBAND CHARACTERISTIC AND FIG. 9(B) IS A GRAPH FOR ILLUSTRATING THE SQUARENESS RATIO VERSUS THE SUBSTRATE CUT ANGLE

ATTENUATION

MINIMUM INSERTION LOSS

1.5 DB BANDWIDTH

20 DB BANDWIDTH

FREQUENCY

SQUARENESS RATIO

ROTATION ANGLE (CUT ANGLE) θ (°)

[FIG. 10]

A GRAPH FOR ILLUSTRATING PASSBAND CHARACTERISTICS OF THE FILTER SHOWN IN FIGS. 7(A) AND 7(B)

ATTENUATION (DB)

FREQUENCY (MHZ)

[FIG. 11]

A GRAPH ILLUSTRATING THE SUBSTRATE CUT ANGLE VERSUS AN ELECTROMECHANICAL COUPLING COEFFICIENT WHEN A $LiTaO_3$ SUBSTRATE IS USED FOR THE FILTER SHOWN IN FIGS. 7(A) AND 7(B)

ELECTROMECHANICAL COUPLING COEFFICIENT K^2

ROTATION ANGLE (CUT ANGLE) θ [°]

[FIG. 12]

A GRAPH FOR ILLUSTRATING THE EFFECT OF AN ELECTRODE FILM THICKNESS FOR A PROPAGATION LOSS, WITH RESPECT TO VARIOUS SUBSTRATE CUT-ANGLES, WHEN A $LiTaO_3$ SUBSTRATE IS USED FOR THE

FILTER SHOWN IN FIGS. 7(A) AND 7(B)

PROPAGATION LOSS (DB/λ)

ELECTRODE THICKNESS (H/λ)

[FIG. 13]

A GRAPH ILLUSTRATING THE EFFECT OF AN ELECTRODE FILM THICKNESS FOR A PROPAGATION LOSS, WITH RESPECT TO VARIOUS SUBSTRATE CUT-ANGLES, WHEN A $LINBO_3$ SUBSTRATE IS USED FOR THE FILTER SHOWN IN FIGS. 7(A) AND 7(B)

PROPAGATION LOSS (DB/λ)

ELECTRODE THICKNESS (H/λ)

[FIG. 14]

FIG. 14(A) IS A VIEW OF THE CONFIGURATION OF A SURFACE ACOUSTIC WAVE FILTER ACCORDING TO A MODIFICATION OF THE FIRST EMBODIMENT OF THE PRESENT INVENTION AND FIG. 14(B) IS AN EQUIVALENT CIRCUIT OF THE MODIFICATION

[FIG. 15]

AN EQUIVALENT CIRCUIT DIAGRAM OF THE SURFACE ACOUSTIC WAVE FILTER ACCORDING TO THE MODIFICATION SHOWN IN FIG. 14

[FIG. 16]

A VIEW SHOWING THE CONFIGURATION OF A SURFACE ACOUSTIC WAVE FILTER ACCORDING TO A SECOND EMBODIMENT OF THE PRESENT INVENTION

[FIG. 17]

A VIEW SHOWING THE CONFIGURATION OF A SURFACE ACOUSTIC WAVE FILTER ACCORDING TO A THIRD EMBODIMENT OF THE PRESENT INVENTION

[FIG. 18]

A VIEW SHOWING THE CONFIGURATION OF A SURFACE ACOUSTIC WAVE FILTER ACCORDING TO A FOURTH EMBODIMENT OF THE PRESENT INVENTION

[FIG. 19]

A VIEW SHOWING THE CONFIGURATION OF A ONE-PORT SURFACE ACOUSTIC WAVE RESONATOR ACCORDING TO A FIFTH EMBODIMENT OF THE PRESENT INVENTION

[FIG. 20]

A VIEW SHOWING THE CONFIGURATION OF A TWO-PORT SURFACE ACOUSTIC WAVE RESONATOR ACCORDING TO A SIXTH EMBODIMENT OF THE PRESENT INVENTION

[FIG. 21]

A GRAPH SHOWING AN EXAMPLE OF A PASSBAND CHARACTERISTIC OF A KNOWN SURFACE ACOUSTIC WAVE DEVICE

LOSS (DB)

FREQUENCY (MHZ)